IMPACTS OF HIGH-SPEED RAIL ON AIRLINES AND AIRPORT TRAFFIC: A SURVEY OF RECENT RESEARCH[1]

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Introduction

The first modern high-speed rail (HSR) – the route between Tokyo and Osaka with a maximum speed of 210 km/hour – went into operation in Japan in 1964. In 1976, British Railways opened an HSR line between London and Bristol. France commenced the operation of its first HSR between Paris and Lyon in 1981. Since then, many European countries have built HSR lines, including Spain, Germany, Italy, Belgium, and the Netherlands. In Asia, Japan remained as the only country operating HSR service until this century, when several economies in East Asia started HSR services. South Korea started its first HSR line between Seoul and Daegu in 2004 (which was, in 2009, extended to Busan), and Taiwan started its HSR service between Taipei and Kaohsiung in 2007. However, the most astonishing development occurred recently in China (e.g., Fu et al., 2012; Givoni et al., 2012). As of 1 October 2018, the total length of HSR tracks in operation in China is 27,684 km, which is 64% of the world's total(UIC, 2018). The HSR network is still fast expanding. According to the new "Mid-and-Long Term Railway Network Plan" announced by the State Council in July 2016, China's HSR tracks will reach a length of 38,000 km by 2025, including eight north-south and eight east-west trunk lines.

A major impact of HSR development is on air transportation: it is clear, at least on a first cut, that both modes are competitors for inter-city passengers of a certain distance range. In effect, about 80% of the Chinese domestic airline routes are to be overlapped with HSR lines by 2025. In this paper, we first briefly review impacts of the air-HSR competition on airlines. The focus is on the overall effects of parallel HSR services on passengers' mode choice as well as on airlines' flight frequencies, traffic volumes, airfares and market power. While many factors may influence inter-modal competition, our review provides an extensive discussion on the impact of HSR speed that relates to not only travel time (given a fixed distance) but also safety concerns. In addition to the competition aspect, HSR may also complement air transport with air-HSR intermodal services. This, together with the network feature of airline business, would substantially complicate the interaction between HSR and air transport. In effect, in some recent studies air traffic increase was observed on certain routes which questions, for example, the effectiveness of using HSR as a policy device to mitigate airport congestion.

The above observation motivates the second, and the key, part of our survey: this part summarizes theoretical and empirical findings on the impacts of HSR on airports. The main insights from our extensive review are: First, HSR can have a traffic redistribution effect on airport traffic: in particular, some primary airports with good air connectivity may gain traffic while others may lose traffic. This distributional inequality may be caused by unequal improvements in accessibility to non-local markets or increased competition between rival airports after the introduction of HSR. Second, to mitigate congestion at primary hub airports, policy makers can consider diverting some traffic to regional airports by promoting air-HSR intermodal services. However, in addition to physical connection between airport and HSR station, appropriate plans to either attract international business activities or convert the airport into an airline's hub need to be provided; here, policy makers can play an important role in ensuring sufficient investments in the intermodal service.

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Impact on Airlines

Effects of air-HSR competition

The earlier stream of the theoretical literature on air-HSR interactions focuses on the competition between airlines and HSR. Here, studies have examined both the short-term and long-term effects of HSR on airfares, profits, and social welfare. Adler et al. (2010) used a game theoretic setting to analyze competition between air transport and HSR in the medium- to long-distance transport market. However, they were unable to obtain the analytical solutions and instead solved the model using a European case study. Adler et al. concluded that the EU should encourage the development of the HSR network across Europe. Yang and Zhang (2012) showed that the airfare tends to fall, whilst the rail fare tends to rise, if the access time to an airport is longer. Airfare is negatively related to rail speed if the marginal cost of HSR with respect to rail speed is not too large. Jiang and Zhang (2016) shedded light on the long-term impact to airlines brought about by HSR. They showed that HSR competition may induce airlines to change their network structure from point-to-point to hub-and-spoke and to cover more fringe markets.

There is a vast empirical literature on the effects of HSR on parallel airline services. A large group of empirical studies focus on passengers' willingness-to-pay, terminal accessibility and modal choice behaviors. For example, González-Savignat (2004) studied the potential for HSR to compete with airlines in the Madrid-Barcelona market and found that impacts on airlines depend on HSR travel time. Roman et al. (2007) analyzed air transport–HSR competition based on a mixed set of revealed-preference and stated-preference data on the Madrid–Barcelona link, and obtained different willingness-to-pay measures for service quality improvement. Martin et al. (2014) also studied the Madrid-Barcelona corridor, and examined the effect that access and egress times to transport terminals have over the spatial modal distribution of the HSR and air transport in the corridor. They extended the previous literature by presenting a detailed spatial analysis of accessibility to terminals, as this is not as simple as just the journey time from the city center of Madrid or Barcelona. The authors showed that easy access by private car tends to favor the relative competitiveness of air transport, whilst easy public transport access tends to favor HSR competitiveness. Behrens and Pels (2012) studied the travelers' behavior in the London-Paris market and found that HSR's frequency and travel time were the main determinants of travel behavior. Martin and Nombela (2007) showed that in Spain, HSR trains would attract travelers from planes and buses on long-haul routes, while trains would mainly attract car users for short-haul routes.

Another group of empirical studies focus on airlines' behavior with route-level data. Most studies have found that competition from HSR has exerted a downward pressure on airfares, flight frequencies, and air traffic (e.g., Albalate and Bel, 2012; Givoni and Dobruszkes, 2013; Dobruszkes et al., 2014; Albalate et al, 2015; Wan et al., 2016; Chen, 2017; Wang et al., 2018). Here, the largest stream deals with European data. By taking a supply-oriented analysis, Albalate et al. (2015) found that airlines reduced the number of seats offered when facing competition from HSR but not the frequency. Jiménez and Betancor (2012) found that on average, the HSR entry has led to a reduction in the number of air operations by 17% in Spain. The previous literature has confirmed that HSR frequency and the number of HSR seats are important factors affecting the outcome of air-HSR competition (Castillo-Manzano et al., 2015; Jiménez and Betancor, 2012). Both Castillo-Manzano et al. (2015) and Jimenez and Betancor (2012) found that air demand is negatively associated with the number of HSR seats.

The second stream of literature focuses on the Chinese market. The spread of HSR network has forced Chinese airlines to slash domestic airfares and reduce or cancel flights. For instance, all the flights between Zhengzhou and Xi'an (the route distance is 505 km) were cancelled by the airlines in March 2010 — 48 days after the opening of HSR service — due to very low demand. Even for the Wuhan-Guangzhou route — a much longer route (1,069 km) — daily airline flights were reduced from 15 to 9, one year after the HSR entry (Fu et al., 2012). Chen (2017) investigated the air-HSR competition on the Wuhan-Guangzhou and Beijing-Shanghai routes and found a significant drop in air traffic, flight frequency and seat capacity after the introduction of parallel HSR services. In particular, air travel declined by approximately 45% after commencement of the Wuhan-Guangzhou HSR, whereas it fell by 34% after the opening of the Beijing-Shanghai HSR. Using a panel dataset from 2007 to 2013 for 138 routes with HSR-air competition, Yang et al. (2018) found that the entry of new HSR services in general leads to a 27% reduction in air travel demand, while Li et al. (2019) suggested a 50% reduction. Li et al. (2018) further identified a strong negative impact of HSR frequency on air travel demand. They also noted that the negative impact of HSR is strong in China's central and western regions. Wang et al. (2017) analyzed whether China should further expand its HSR network considering the role of low-cost carriers (LCCs) as an alternative transport mode. The authors called for a more careful evaluation of the program and, more generally, a balanced and coordinated HSR and LCC development in China.

Besides extensive literature on the European and Chinese markets, there exist studies in other regions as well. For example, the opening of Shinkansen in Japan reduced air passenger traffic significantly, and the introduction of Korean Train Express (KTX) in 2004 affected both passenger demand and airfare (Vickerman, 1997; Suh et al., 2005; Chang and Lee, 2008). Using the stated-preference survey method, Park and Ha (2006) showed that the opening of KTX imposes significant competitive pressures on airlines in South Korea's domestic market. Wan et al. (2016) investigated the effects of HSR on airlines in China, Japan, and South Korea. The authors found that the entry of HSR had strong negative impacts on short-haul and medium-haul air routes seat capacity in both China and Japan.

Effects of HSR speed

Most studies found that the HSR is a strong competitor of air transport on short- and medium-distance routes (Gonzalez-Savignat, 2004; Givoni and Banister, 2006; Hu et al., 2015). HSR is found to be the dominant transport mode for travel distance between 300 km to 700 km (Fu et al., 2014; Román et al., 2007; Wan et al., 2016; Yamaguchi et al., 2008), whereas air transport is found to be the dominant mode, with market share varying between 50-80%, on travel distances over 1,000 km (Givoni, 2006; Janic, 2003). However, Rothengatter (2011) pointed out the distance that has a fierce competition between civil aviation and HSR is from 400 to 800 km. Zhang and Zhang (2016) used gravity models to examine the determinants of air passenger flows in China with the HSR presence as one of the explanatory variables and found that the distance of air routes that are subject to HSR competition could extend to as long as 1,300 km. These seemingly contradictory findings about the dominant distance range of air transport over HSR is not that surprising, because what matters more is the actual travel time – the HSR train speed can vary significantly in different markets and during different time periods.

Existing studies almost exclusively focus on the travel-time effect of HSR speed on airlines. For example, theoretical papers by Yang and Zhang (2012) and Xia and Zhang (2016) investigated how travel times of HSR and airlines can affect passengers' choice of travel modes. In an empirical study, Dobruszkes (2011) recognized HSR travel time as the key competitive factor in air-HSR competition in the Western European market. An EU-wide study by Dobruszkes et al. (2014) reported that air services are affected by HSR travel time, i.e., the longer the HSR travel time, the more air services. Capozza (2016) tested HSR travel time on airfare using the market data of Italy and found that airlines set, on average, higher fares as rail travel time increases. Zhang et al. (2017a) also found that airline demand decreases with shorter HSR travel time in the Chinese market. Li and Loo (2017) found that airline demand in China decreases with the increase of railway speed (i.e., shorter rail travel time), but this effect only manifests on short-haul routes (less than 1,100 km as defined in the paper). Jorritsma (2009) concluded that the HSR occupancy rate could reach 50%-90% if travel time of HSR is within 2 to 3 hours. Clewlow et al. (2014) found that the improvement of rail travel time has a significant impact in reducing short-haul air traffic.

There are two empirical studies that examined explicitly the effects of HSR travel speed on Chinese airlines. Wei et al. (2017) investigated the HSR substitution for air travel through the demand shocks triggered by two railway events: the launch of Beijing-Shanghai HSR and the Wenzhou train accident.

The two events are exogenous to the airline industry, alleviating the common endogeneity concern. Using airline ticket prices published on a booking agency website and a difference-in-differences (D-in-D) approach, the authors found some evidence of substitution based on the pattern of airfare adjustments during the sample period. Specifically, compared to those in the control group, mean airfares for routes along the Beijing-Shanghai HSR route decline by 30.4% upon the launch, but rebound by 27.4% following the accident. Furthermore, the two events have a larger impact on LCCs and regional airlines, on tourism routes, and on flights that depart during evening hours than their respective counterparts. They concluded that the HSRs mainly serve as a low-end substitution for air travel in China.

Wang et al. (2018) studied the effects of HSR travel speed on airline demand, equilibrium airline traffic and price both theoretically and empirically. Their empirical study applied the D-in-D method to a rare natural experiment of HSR speed reduction in China. The authors found: (i) the "travel time" effect due to HSR change dominates the "safety" effect – while increasing HSR speed reduces HSR travel time and thus lowers airline demand (the travel-time effect), it may bring about a safety concern especially in emerging HSR markets such as China.(the safety effect) – leading to a negative HSR speed effect on airlines; (ii) the elasticities of the airline demand and equilibrium airline traffic and price with respect to HSR speed are larger in magnitude on short-haul routes than on medium-to-long-haul routes; (iii) the entry of HSR on short-haul routes has larger negative impacts on airline demand and equilibrium airline traffic and price than on medium-to-long-haul routes; and (iv) there is a positive and statistically significant accident effect with daily data, but this accident effect is small in magnitude and vanishes with quarterly data.

Effects of HSR on airfares and airline market power

HSR entry may effectively reduce airlines' market power and hence airfares via air-HSR competition. Ma et al. (2018) examined such effects using the busiest and most profitable HSR line in China (between Beijing and Shanghai) that parallels airline service. The authors found that both airfare and air demand fell significantly after the entry of Beijing-Shanghai HSR. In particular, economy-class airfares dropped more than business-class airfares but, somewhat surprisingly, the decline in the business-class demand was larger than that in the economy-class demand. Although HSR frequency and the number of HSR seats appeared to have no significant impact on airfares, they were significantly and negatively associated with air demands, especially the demand for business passengers. Zhang et al. (2017a) found a negative relationship between airfare and HSR frequency in China. However, the authors argued that the impact of HSR frequency on airfare is much weaker than the impact of HSR travel time. HSR services are more punctual than airline services and are less likely to be affected by bad weather conditions (see also Chen and Wang, 2018).

Zhang et al. (2014) used Lerner index to measure the market power of Chinese airlines and found that HSR is one of the most important determinants of airline market power. Zhang et al. (2018b) examined the impact of HSR on market concentration (HHI) and Lerner index in China's airline market. They found that in general, the entry of HSR had the effect of reducing market power measured by both the unweighted and weighted Lerner indexes. On the other hand, the Lerner index and HHI of the routes with parallel HSR services remained consistently higher than those of the routes without parallel HSR services, suggesting that HSR also has an effect on airline market structure. Qin (2018) found that the introduction of HSR increases airline concentration (HHI) measured by the number of routes operated by individual airlines in a Chinese city. Due to low air-to-air connectivity, airlines with weaker presence in the city are more likely to exit rather than compete with HSR and as a result, the share of the city's dominant carriers increases.

Effects of air-HSR cooperation

In addition to air-HSR competition, an emerging body of theoretical literature focuses on air-HSR cooperation in offering air-HSR intermodal transport services. For example, Jiang and Zhang (2014) considered the cooperation between HSR and air transport under hub airport capacity constraint. Xia and Zhang (2016) investigated the competition and cooperation between HSR and air by adopting a vertical differentiation approach and found that in the HSR-inaccessible market, HSR-air competition may lead to higher airfares in the connecting market. This stream of literature remains largely theoretical. We will leave a thorough review on air-HSR cooperation (including its impact on profit and welfare) in future studies while only discussing papers explicitly analyzing its impact on airport traffic in the next section.

Impact on Airport Traffic

Since HSR serves as an effective substitute to short/medium-haul air flights, one may predict that air traffic will fall after the introduction of HSR services. This prediction appears to play a key role in many policy makers' arguments for using HSR, or air-HSR intermodal transport, as a solution to airport congestion and to excessive emissions from air flights. As we discuss below, this conclusion might be reached too fast.

In fact, that air traffic rises on routes with overlapping HSR services has been observed in several recent studies. Albalate et al. (2015) compare three types of air routes with parallel HSR services: (i) routes with a hub airport as an endpoint and an on-site HSR station at the hub airport; (ii) routes with a hub airport as an endpoint but no on-site HSR station; and (iii) routes without a hub airport as an endpoint. They found negative (in general) but statistically insignificant impacts on the routes with hubs and on-site HSR stations (e.g., Paris-CDG and Frankfurt) and strong, negative impacts on the routes with hubs but no on-site HSR stations (e.g., Paris-Orly, Madrid, Rome, and Milan). However, on the routes linking two spoke airports, they found a much milder or even positive impact in France, Spain and Italy, but a strong, negative impact in Germany. In long-haul markets, although most studies found little impact on air traffic after the parallel entry of HSR, significant air traffic increases were observed in China on routes over 800-1,000 km (e.g., Wan et al., 2016; Zhang et al., 2018a). Qin (2018) also observed an increase in the number airlines on certain overlapping long-haul routes. More surprisingly, according to Qin (2018)'s simulation study, airlines may also drop routes without parallel HSR service (i.e., not directly competing with HSR). In other words, to understand the impact on airports, one must take into account the network nature of airline business as well as both the substitution and complementary impacts of HSR.

The provision of air-HSR intermodal service would substantially complicate the picture, because air traffic might be affected not only in the overlapping markets, but also in the segments that HSR is unable to access (for example, inter-continental air travel). Intuitively, HSR may increase air traffic on the HSR inaccessible route segments if HSR can effectively extend the airport's catchment to areas which used to be underserved by air transport due to high ground access cost. However, if HSR connects two airport cities, it may intensify the competition between those airports and one may question if the smaller airport will be disadvantaged, as the larger airport may have better international connection and hence can attract more passengers flying to international destinations from the smaller airport.

Impact of air-HSR cooperation (theoretical studies)

Several theoretical studies have discussed, either directly or indirectly, the impact of HSR on airport traffic by taking into account air-HSR intermodal services, but none have compared the (equilibrium) outcomes before and after the HSR entry. These studies have instead evaluated how air-HSR cooperation (or integration) would play a role. The net effect of air-HSR intermodal cooperation on an individual airport could depend much on the airport's accessibility to HSR inaccessible markets, its attractiveness to passengers from the competing airports, as well as changes in market structure of the city-pair markets. The basic modeling framework can be traced back to Socorro and Viecens (2013) and has been modified in various follow-up studies.

<u>1) Unequal access to HSR inaccessible markets</u>
Figure 1 illustrates the basic network structure used in this stream of literature. There are three cities (denoted as A, B and H) and three city-pair markets (AH, HB and AB) in the network. In the baseline setting, HSR connects two cities, one with a hub airport (H) and the other with a spoke airport (A). Airlines offer non-stop service in the AH and HB markets while the AB market is served by connecting flights in AH and HB segments via H. That is, city B (the third region that is not feasible for HSR service) is only accessible by airport H but not by airport A. HSR service, on the other hand, is only available in the HB market, but it is possible to combine HSR service in the AH segment and air service in the HB segment to serve the AB market. A real-life example would be a network of Valencia, Spain (for A), Madrid, Spain (H), and Hong Kong (B).

Figure 1 Network structure applied in the theoretical literature

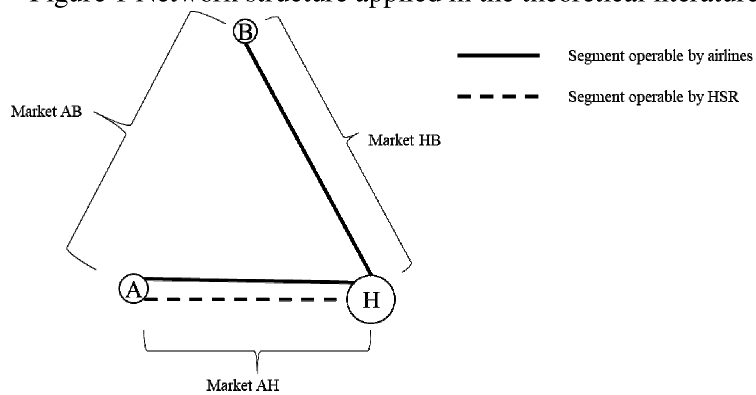

Table 1 lists the various settings applied by representative papers that assume HSR connects a hub airport and a spoke airport (as depicted in Figure 1). Air-HSR cooperation is mainly modeled by having the airline and HSR jointly maximize profit and set quantity (or price) for the air-HSR intermodal product in the AB market. Note that the last column is the case in which an airline and HSR make decisions separately, but the quality of the air-HSR option is improved by a shortened transfer time between the airport and HSR station. The traffic impact in individual city-pair (OD) markets depends much on model settings, including the number of airlines in the HB market, the accessibility of the cooperating airline to the AH market, the availability of air-HSR option in the AB market prior to the cooperation, the availability of air-air option in the AB market after the cooperation, and other differences in detailed model assumption. The traffic impacts summarized in Table 1 are based on the case of no airport capacity constraint.

All the papers in Table 1 study a case where the hub airport H becomes more accessible to the AB market after air-HSR cooperation or quality improvement, while airport A remains inaccessible to the AB market (i.e., no direct flights between A and B). In most of the cases air traffic in the AB market tends to rise, due to the improved access with HSR's traffic feeding, and this drives up air traffic on the HB segment. Air traffic in the AH market is likely to fall.

However, the above does not always hold (e.g., Xia and Zhang, 2016).When the air-HSR connection at the hub is improved, a reduction won't necessarily occur in the AH market (e.g., Xia and Zhang, 2016). This theoretical prediction appears consistent with the empirical finding of insignificant traffic reduction on the routes linked to hub airports with on-site HSR station in Europe (Albalate et al., 2015). Air traffic in the seemingly irrelevant HB market may increase or decrease (e.g., Xia and Zhang, 2016). Most of the papers do not provide explicit assessment on total traffic on each route segment or the net impact on total airport traffic. However, the mixed results on city-pair markets suggest a high chance of having mixed results on route segments and airport traffic. In general, traffic at spoke airport A is very likely to fall while a net traffic increase at airport H is promising. Both airport A's lack of connection to HSR inaccessible region (B) and the unilateral accessibility improvement at airport H contribute to airport A's failure to counteract the substitution effect of HSR. In fact, based on a model similar to Jiang and Zhang (2014), Avenali et al. (2018) show that an increase in the airport H's total traffic will occur under certain conditions.

Table 1 Summary of traffic impacts of air-HSR cooperation (without airport capacity constraint)

Paper		**Socorro and Viecens (2013)**		**Jiang and Zhang (2014) / Sato and Chen (2018)**	**Xia and Zhang (2016)**	
Number of airlines / Form of cooperation		One airline / Joint decision making	Two airlines A1, A2 / Joint decision making (A2 + HSR)	One airline / Joint decision making	Two airlines A1, A2 / Joint decision making (A1 + HSR)	One airline / Reducing air-rail connecting time
Market structure of each OD market before and after integration	AH market	Before: Duopoly (air, HSR) After: Monopoly (HSR)	Before: Duopoly (A1, HSR) After: Duopoly (A1, HSR)	Before: Duopoly (air, HSR) After: Monopoly with two products (air, HSR)	Before: Duopoly (A1, HSR) After: Monopoly with two products (A1, HSR)	Before = after: Duopoly (air, HSR)
	AB market	Before: Monopoly (air-air) After: Monopoly (air-HSR)	Before: Monopoly (A1-A1) After: Duopoly (A1-A1, A2-HSR)	Before: Monopoly (air-air) After: Monopoly with two products (air-air, air-HSR)	Before: Competition among three products (A1-A1, A1-HSR, A2-HSR) After:Monopoly with two products (A1-A1, A1-HSR)	Before = after: Duopoly (air-air, air-HSR)
	HB market	Before: Monopoly (air) After: Monopoly (air)	Before: Duopoly (A1, A2) After: Duopoly (A1, A2)	Before: Monopoly (air) After: Monopoly (air)	Before: Duopoly (A1, A2) After: Duopoly (A1, A2)	Before = after: Monopoly (air)
OD market traffic impact	AH market (air traffic)	Reduce to zero	Unchanged	Decrease due to reduced competition (Jiang and Zhang, 2014); May or may not decrease (Sato and Chen, 2018)	Not discussed, but air fare increases while HSR fare may or may not increase, so reduction is possible	Mixed
	AB market (air-air and air-HSR)	Increase due to efficiency gain from air-HSR integration (HSR is assumed to be less costly to operate)	Increase due to competition in AB market (air-air reduce, air-HSR increase)	Increase due to introduction of air-HSR product (Jiang and Zhang, 2014); Net effect not discussed in Sate and Chen (2018)	Not discussed, but both air-air fare and air-HSR fare increase so likely to decrease	Increase (air-air increase, air-HSR may increase or decrease)
	HB market (air traffic)	Unchanged	Unchanged	Unchanged	Increase due to price reduction of A1	Decrease due to air fare increase to make air-HSR mode more expensive

2) Dual access to HSR inaccessible markets

Another stream of papers extends the above model to study the interaction between two hub airports, both accessible to the third region (B). Takebayashi (2015) models a system of two airports of interest (A and H) by adding an air link on the AB segment in Figure 1. Airports H and A compete for international passengers destined to city B (the third region not accessible by HSR); as such, H and A may be referred to as "gateway airports". As city centers of these two airports are linked by HSR, travelers in city A (city H, respectively) can take a flight from airport H (airport A, respectively) with an HSR ride. Everything else being equal, airport A has weaker access to the HSR station (e.g., higher airport-HSR station connection cost). He finds that compared with airport H, airport A will serve more air-air connecting passengers but fewer air-HSR connecting passengers, fewer passengers taking direct flights in the AB market, and consequently fewer total passengers. If airport H is a larger gateway hub with higher demand for international flights (HB) and airport A is a smaller gateway with lower demand for international flights (AB), airport H tends to be more attractive to passengers who want to fly to city B, since larger demand can be translated into higher flight frequency on the HB segment. However, lowering the connection cost between the smaller airport (A) and the HSR station in its city center may substantially improve the small airport's gateway position in terms of attracting international passengers from the larger airport by air-HSR connecting service. Moreover, this type of improvement is more effective when the demand difference between the airports is larger.

Takebayashi (2016) extends the model by investigating the role of airport-HSR cooperation in diverting traffic to the smaller airport (A) and thus mitigating congestion at the larger gateway airport (H). The airport-HSR cooperation is in the form of maximizing airport-HSR joint profit and subsidizing international passengers who choose an air-HSR intermodal service. He concludes that cooperation between HSR and the larger gateway airport is not desirable, but cooperation between HSR and the smaller airport is desirable. Basically, in this multi-airport system cooperation with the larger airport simply increases connecting passengers, especially air-HSR passengers; these connecting passengers will displace non-stop passengers and reduce system-wide total traffic (A+H). Furthermore, the larger cooperating airport might attract too many air-HSR connecting passengers, thereby worsening its congestion. On the other hand, cooperation with the smaller airport not only increases the system-wide connecting passengers but also total air traffic in the multi-airport system.

Xia et al. (2018a) apply a similar network setting, but with substantial simplifications, to focus on the incentives to form partnership by the HSR and airports. They assume: (i) HB is the only OD market in concern; (ii) cities A and H are linked only by HSR (due primarily to the distance being too short to fly); (iii) each airport forms a single entity with all the airlines operating at the airport, i.e. air sector H and air sector A; and (iv) air-HSR cooperation is only feasible between HSR and air sector A. A new feature is that their cooperation scheme includes air sector A's reimbursing HSR tickets to air-HSR passengers, and HSR's sharing ticket revenues with air sector A. This cooperation scheme is shown to achieve a better traffic distribution by diverting some traffic from the busier airport to the smaller airport, and to improve consumer surplus as more passengers will travel in market HB. They also find that social welfare tends to rise especially when congestion at the larger airport is severe, but that profits of air sectors and HSR may increase or decrease. Therefore, despite the positive impacts on airport traffic, consumer surplus and social welfare, this type of air-HSR cooperation may not arise automatically. They further show that cooperation tends to be achieved when the HSR operator is welfare-oriented or when air sectors A and H are monopolized. As the Chinese case fits these conditions to some extent, they predict this type of air-HSR cooperation to appear in China. In the context of private HSR operators and highly competitive airports, such as the case of Europe, this type of cooperation is less likely to occur and may require policy interventions.

Airport traffic redistribution effect of HSR

The above literature review suggests that HSR can have a "traffic redistribution" effect on airports. Traffic might be more evenly distributed among airports in certain cases whilst, in other cases, becoming more concentrated at a few major airports. Roughly, there are three mechanisms through which the distributional inequality is increased (or reduced):

(i) When the feeding role of HSR is negligible, all airports may suffer traffic loss, while those airports with better flight connections (e.g., hubs) may suffer less than the others.
(ii) When the HSR's feeding role is present, airport traffic distribution can be affected by unequal improvements in accessibility to non-local markets, especially those inaccessible by HSR. All the papers reviewed in the previous section fall into this category, where market HB is the non-local market for airport A and market AB for airport H. Regardless of model settings, they all consider a case that one airport enjoys a better accessibility improvement than the other. Unsurprisingly, if larger and well-connected airports receive more accessibility improvement than the others, these larger airports will experience more favorable traffic change than the smaller ones. Note that this "favorable traffic change" is relative to other airports. It may not indicate a net traffic increase at the airport since the substitution effect of HSR can be too strong to overcome, but the distributional inequality is likely to be enhanced. Of course, airport traffic might be more evenly distributed if only

small airports' accessibility improves. Xia et al. (2018a)'s model provides one example of improving small airports' access to a market originally served only by the large airport. Their analysis shows that this type of airport-HSR cooperation is difficult to achieve as it may not be profitable for airports and HSR, though a better traffic distribution can be achieved together with an enhanced social welfare.

(iii) The last possible mechanism plays a role when HSR does not cause differentiated improvement in accessibility but helps potentially rival airports to access each other's catchment and increase competition. Then, intuitively airports with larger size (and better flight connectivity and higher frequency) are likely to win traffic from the weaker ones, due to the economies of scale and network size. Nevertheless, if the larger airports are highly congested, unsatisfied travel demand may spillover to the smaller airports which can be easily accessed by HSR, as the diseconomies of scale arises. To our knowledge, this impact of HSR has yet been explicitly explored, analytically or empirically, in the air transportation literature. Takebayashi (2015, 2016) models two competing hub airports, but the analysis is limited to asymmetric accessibility change as mentioned in the second point and hence provides little insights on the third mechanism.

In practice, more than one mechanism may be simultaneously at work, and it is therefore important to measure the HSR's impact on airport traffic empirically. Here the literature is much smaller than the literature on route-level impacts (airport pairs or city pairs).

Based on interviews and case studies, Clewlow et al. (2012) find that at the Paris-CDG and Frankfurt airports, domestic traffic declined while international traffic increased due to the integrated air-HSR services. To our knowledge, Clewlow et al. (2014) provide the first airport-level regression analysis with data from Europe. They find a strong negative impact on domestic air traffic, but a much milder or even insignificant negative impact on intra-EU traffic and total traffic. Similarly, Zhang et al. (2017b) calculate the flight connectivity of 69 Chinese airports and identified the underlying drivers of the variation in airport connectivity over a period 2005–2016. The authors find that HSR has the effect of decreasing the overall and domestic airport connectivity due to its high substitutability for air transport but its impact on international connectivity is statistically insignificant. By including all Chinese airports in their study, Li et al. (2018) find that on average HSR reduced air passenger growth rate by 8.5% in 2015 but rapid economic growth can make air traffic continue growing. Castillo-Manzano et al. (2015) propose a dynamic linear regression approach and estimate how the expansion of the Spanish HSR system (measured by the number of HSR passengers in the entire HSR system) over time has affected the domestic air passenger traffic at the Madrid-Barajas airport. The study reveals a negative effect of the HSR passenger number on domestic airport traffic. Moreover, from January 1999 to the end of 2007, as new HSR lines linking less populated cities were added into the system, the degree of such airport-traffic reduction diminished. As a result, in the 1999-2012 period, only 13.9% of HSR passengers were diverted from air transport. Based on this finding, the authors question the existence of HSR network effect in terms of attracting passengers away from air transport.

The above studies focus on the net impact on a specific airport or the average impact on a sample of airports, after balancing the substitution and complementary effects, but they provide little insight on spatial inequality of airport traffic. Some recent empirical studies tried to better quantify the impacts by distinguishing substitution and complementarity between air transport and HSR (e.g., Qin, 2018; Zhang et al., 2018a; Liu et al., 2019). Instead of studying the impacts on air traffic, Qin (2018) focuses on airlines' domestic route entry behaviors in China. The substitution effect is found to dominate the complementary effect, leading to an overall reduction in the number of routes operated by airlines. Cities (airports) located in Central and Eastern areas of China are mostly affected due to a high percentage of air routes encountering parallel HSR services. Improving the positive spillover from HSR can effectively increase airlines' route presence if the city has a moderate level of HSR connections.

Zhang et al. (2018a) add to this stream of literature by estimating the impact of on-site HSR stations on the airport-level traffic using airport data from both East Asia and Central Europe. By focusing on the feeding (complementary) effect of HSR on airport traffic, the authors are able to capture the differential impacts of HSR on airports. They find that on-site HSR stations increased air traffic at primary hub airports while the impact on secondary hubs and regional airports was insignificant. Furthermore, the impact at hub airports is stronger in Central Europe than in East Asia. This finding suggests that a possible inequality in the HSR's accessibility improvement effect may exist between the primary and secondary hubs at a world-wide scope. However, Zhang et al. (2018a) do not compare the net traffic impacts between the hub and non-hub airports by also taking the substitution effect into account.

Liu et al. (2019) do compare the net traffic impact; moreover, they consider the spatial difference of airports' location in the HSR network. Using the detailed HSR timetable data in China and Japan, they calculate both the "degree centrality" and "harmonic centrality" of an airport's city within the national HSR network to reflect, respectively, the connectivity and accessibility of the city to other cities with HSR. They also identify the potential complementary effect of HSR by including an interaction term between the centrality measure and the presence of a convenient airport-HSR station transfer linkage. In general, in the case of China, as the connectivity or accessibility grows, hub airports experienced a net traffic growth, while non-hub airports experienced a strong traffic reduction. Such traffic growth at a hub airport is even more substantial with a good airport-HSR station linkage. The main source of traffic increase comes from HSR's feeding to international flights and little change in domestic traffic. The traffic-reduction effect at non-hub airports mainly comes from the domestic traffic reduction and a limited change in international traffic. Adding an airport-HSR station linkage did not help a non-hub airport to grow traffic a lot (both domestic and international), but it might be helpful to balance the substitution and feeding effects since the net effect of improved HSR connectivity tends to be statistically insignificant at non-hub airports with airport-HSR station linkage. In Japan, however, both centrality measures were found to have little impact on domestic traffic but they had some positive effect on international traffic. Furthermore, regardless the hub status, having airport-HSR station linkage helped to boost international traffic in Japan, although the effect on non-hub airport was much smaller.

Liu et al. (2019)'s finding suggests an increased inequality of traffic distribution between the hub and non-hub airports in both China and Japan, since hub airports seem to be more favored by HSR entries than non-hub airports (Sun et al., 2018). This finding is consistent with that of Zhang et al. (2018a). Furthermore, Liu et al. (2019) discover a net traffic loss at non-hub airports and a net traffic increase at hub airports, thus suggesting a possible traffic diversion from the non-hub to hub airports in China. Although this finding sheds some light on the third mechanism discussed above, it provides no direct evidence on the presence of this mechanism. One may come up with another explanation. For example, the traffic loss at non-hub airports can be simply caused by the HSR substitution effect while the traffic gain at hub airports may be contributed mainly by an induced (instead of diverted) demand for international or long-haul flights which would not exist without HSR.

Policy Relevance of Airport-Traffic Effects

Empirical findings discussed above question, at least indirectly, the effectiveness of using HSR to mitigate airport congestion. The possible traffic redistribution (or probably diversion) from non-hub to hub airports (Liu et al., 2019) and more concentrated traffic at hub airports (Zhang et al., 2018a) may worsen the already low "cost recovery" ability of small, regional airports while at the same time exacerbate congestion at large hubs. The possibility of increasing distributional inequality appears much lower in the developed regions, such as Europe and Japan, than in China.

Furthermore, the high level of regional inequality in economic development that has prevailed in emerging economies, such as China, may contribute to the increased inequality in airport traffic. This is because HSR may facilitate the exploitation of agglomeration economies and, consequently, attract more business activities at a few major cities. As primary hub airports usually locate in these well-developed cities, the increased economic activities further stimulate air travel demand at primary airports. This negative traffic-redistribution effect of HSR development warrants more attention in policy debate concerning HSR. Relatedly, policies that favor the regional airports that are negatively affected by HSR may be useful to achieve a better traffic distribution among airports, instead of further expanding a few large hub airports.

Moreover, given that a good air-HSR intermodal linkage (e.g., airport on-site HSR station, airline-HSR cooperation, etc.) tends to make airports suffer a less traffic drop or enjoy a more traffic gain, policy makers may consider this as a tool to achieve a better airport traffic distribution. For example, air-HSR intermodal service can be encouraged at small airports while discouraged at large airports. Of course, promoting the air-HSR intermodal service alone may not be enough; the "small airport" in concern must add sufficient connections to international destinations so as to attract passengers away from the primary airport. This requires a strong local travel demand, which in turn would require the city of the "small airport" to have sufficient economic activities and income levels. Some local governments may try to stimulate international traffic by subsidizing these flights, but it is not sustainable unless the local demand can surge within a short period of time. China has been heavily subsidizing direct intercontinental flights out of second-tier cities (such as Chengdu, Shenyang, Xi'an, and Hangzhou) over the past several years. The total subsidy (eligible for both domestic and foreign operators) was USD1.3 billion in 2016 (Bloomberg News, 2017). However, several foreign airlines have dropped these services since 2016, possibly because demand failed to grow to a satisfactory level by the end of the subsidizing period. The key point is: On-site HSR and other policies that promote air-HSR intermodal service only provide a potential for connection and traffic movement. However, such a potential won't be realized if the local economy is too poor to be worthwhile for a connection (Campante and Yanagizawa-Drott, 2018). Therefore, to divert excessive traffic out of congested primary hubs, secondary airports located in cities with very low income and low growth potential should not be targeted. Meanwhile, appropriate plans to either attract international business activities or convert the airport into an airline's hub should be provided, together with air-HSR promotions.

To improve the connection between the airport and HSR station whenever desired, sufficient incentives should be provided to railways and the air sector, because extra investment is needed to link the airport to the HSR network (Givoni and Banister, 2006). Theoretically, when the airport's runway capacity is severely constrained, both the air and rail operators may benefit from improving air-HSR connection, together with an increase in consumer surplus and social welfare (Xia and Zhang, 2017). Therefore, airlines and railways have strong incentives to invest in the air-HSR intermodal infrastructure by themselves. However, when the runway is not seriously congested, the issue is more complicated. Air and rail operators have low incentives to invest in the intermodal connection despite the gain in consumer surplus and social welfare, because these two modes compete in certain markets (Xia and Zhang, 2017). Of course, if they cooperate, sufficient joint profit can be achieved and shared between the two to induce their investment, but the reduced competition could harm consumers. In this case either a public entity should invest in the intermodal infrastructure, or the regulators should assess the trade-offs before approving the cooperation on investing air-HSR connection and if approved, then monitor the investment ex-post.

References

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